

# Simulation based Performance Analysis of an End-of-Aisle Automated Storage and Retrieval System

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**Abstract:** This paper presents and discusses simulation of an End-of-Aisle automated storage and retrieval system, using FLEXSIM 6. The objective of the simulation model is to analyze and compare results of different control policies and physical designs. The performance measures considered for the evaluation of each control policy and layout combination are the total travel time of the crane and the number of storage and retrieval operations performed. The experiments set up and the corresponding results are discussed.

## 1 INTRODUCTION

Automated storage and retrieval systems (AS/RS) are widely used in manufacturing facilities, distribution centers and warehouses. An AS/RS system is defined as a storage system that uses fixed- path storage and retrieval machines (cranes), running on one or more rails between fixed arrays of storage racks. (Automated Storage Retrieval Systems Production Section of the Material Handling Industry of America, 2005). In such systems, stock keeping units (SKUs) arrive at an Input station from which they are moved by a crane to their storage location. In case of retrieval, the crane transports the SKUs from their storage location to an Output station. AS/RS have both some advantages and disadvantages. The effective use of an AS/RS may lead to substantial savings for a company by reducing direct and indirect labor, energy, maintenance, and building costs (Sarker et.al., 1995). Apparent disadvantages are high investments costs (approximately \$634,000 for a single aisle AS/RS), less flexibility and higher investments in control systems (about \$103,000), (Zollinger, 1999).

In designing an AS/RS, both physical design and control policies must be carefully considered to fully take advantages of its positive impact. On the one hand, the physical design consists of two aspects. First, the AS/RS type has to be chosen; this is what is called the system choice. Secondly, the chosen system must be configured, for example,

by deciding on the number of aisles and rack dimensions; this is called the system configuration. On the other hand, the control policies are methods which determine the actions performed by the AS/RS (e.g., storage assignment, dwell point policy), (Roodbergen, 2009). An AS/RS is usually hired for transporting unit loads (e.g., fully loaded pallets) within the system; but, in many cases, only part of the unit-load may be needed to fulfill a customer's order. A common option to resolve this situation is when the AS/RS drops off the retrieved unit loads at a workstation at the end of the aisle. An operator at this workstation takes the required amount of products from the unit- load, and the AS/RS moves the remainder of the load back into the storage rack (Figure 1). This system is often referred to as an End-of-Aisle (EOA) system. If the unit-loads are bins, then the system is generally called a miniload AS/RS (Roodbergen, 2009). In this study various design scenarios for End-of-Aisle automated storage/retrieval systems are evaluated via simulation.

## 2 LITERATURE REVIEW

Hausman et al., (1976) initiated evaluation of performance in AS/RS systems using analytical and empirical methods. Specifically, they addressed the problem of optimal storage assignment with considering two main policies: randomized storage and class-based storage.

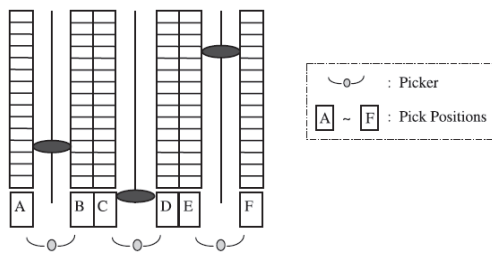


Figure 1: End-of-Aisle AS/RS order picking system (Hwang et al., 2002).

They showed that significant reductions in S/R machine travel time are achieved from turnover-based storage rules such as a class-based storage policy. Accordingly, Bozer and White (1984) developed a continuous rack configuration to evaluate single and dual travel times for rectangular racks and variety of I/O configurations. Furthermore, Han et al., (1987) illustrated that by sequencing the retrieval orders, the throughput performance of the AS/RS can be improved. This can thus reduce the interleaving travel time between storage and retrieval locations in a dual command cycle.

For simulation models in AS/RS, most of the researchers only evaluated some of the physical design aspects in combination with a limited number of control policies. Meller and Mungwattana (2005) applied simulation to evaluate the benefits of different dwell point policies. The results indicate that the position of dwell point has a negligible effect on system respond time when the AS/RS has high utilization. Randhawa and Shroff (1995) examined the effect of different sequencing rules on six layout configurations (with varying I/O-point, item distribution over racks, rack configuration and rack dimensions). Based on a limited number of experiments they mentioned in their study that the position of I/O point at the middle of the rack results in a higher throughput. Vanderberg et al., (2000) have developed a simulation study and examined various aspects of AS/RS control policies: storage location assignment policies, request selection rules, open location selection rules and urgency rules. Considering randomized storage and class-based storage, they concluded that using a FCFS sequence for the retrievals by implementing urgency rules result in better expected time. Randhawa et al., (1991) used simulation to evaluate single and dual I/O point configurations in a unit load AS/RS and their model demonstrated that the dual dock layout maximizes the throughput.

In an End-of-Aisle AS/RS, current retrieval

operation become next storage operation, since loads are returned into the system after items have been picked. A mathematical model to investigate the performance of an EOA order picking systems have been proposed by Bozer and White (1996). They provided some approximate expressions for the expected travel time for systems performing under peak demand, and presented a design algorithm in order to calculate the minimum number of miniload aisles needed to meet a given throughput requirement. Foley and Frazelle (1991) have developed an exact solution for the S/R machine travel time under the FCFS retrieval policy in order to evaluate the throughput for the miniload AS/RS. Hwang et al., (2002) proposed the design of miniload AS/RSs in combination with Automated Guided Vehicles. To recognize the optimal number of loads transferred by each AGV to machines, a non-linear model and heuristics have been developed in their research.

To the best of our knowledge, there is no simulation model for the End-of-Aisle system, therefore in this study a multitude of physical design aspects and control policies are simultaneously included for the End-of-Aisle system.

### 3 SIMULATION MODELING OF THE SYSTEM

#### 3.1 Assumptions

In the system analyzed, a crane serves a single aisle with storage racks placed on one side of the aisle. All storage locations are identical in size and each location can hold one unit load. The total capacity of the system is 100 unit loads. Each unit load (e.g., pallet) contains a number of boxes of one item type. Although the pallet sizes are constant, the size of the boxes on the pallets are different for different item types. The crane's pick-up and deposit time is calculated according to the size and number of boxes inside the pallet; for pallets with a higher number of boxes and larger boxes, the time for pick-up and deposit is higher. Moreover, the times for manual loading and unloading boxes from pallets are calculated according to the boxes' dimension.

The turnover of each itemtype is known in advance and is the same for all scenarios tested. The crane scheduling rule in this study is FCFS (first come, first serve) for both storage and retrieval operations. The capacity of the crane is

one pallet and the crane can move horizontally and vertically simultaneously. Crane acceleration and deceleration are assumed instantaneous. The actual travel time equals the maximum of the horizontal and vertical travel time (Chebyshev distance metric).

A unit-load AS/RS can perform in two ways, namely in a single command cycle or in a dual command cycle. In a single command cycle the crane operates either a single storage or a single retrieval operation. The storage cycle time then is equal to the sum of the time to pick-up a load at the input station, the time to travel to the storage location, the time to place the load in the rack and the time to return to the input station. The retrieval cycle time can be defined similarly. A dual command cycle can be defined as performing both a storage and a retrieval request simultaneously in a single cycle. In this case, the cycle time is defined as the sum of the time to pick up the load, the time to travel to the storage location and store the load, the empty travel time (interleaving time) from the storage location to the retrieval location and the time to pick the unit-load and transport it to the output station. In this study the crane can perform both single and dual command. This means when both storage and retrieval orders are in the queue, the crane performs in dual command but when only a storage order or a retrieval order is available, the crane moves in single command.

If the pallets' arrival rate is very high, the system will be completely operating on dual command, while by reducing the arrival rate, single- and dual- command cycles will be combined in the system. To provide a better basis for analyzing the system, in this study five scenarios for arrival of pallets to the system are assumed. Arrival rates are 25, 40, 60, 80 and 100 per hour respectively.

To study the End-of-Aisle system described, we simulated storage and retrieval for a number of different scenarios. In the following sections, we give an overview of the factors included.

### 3.2 Configurations of Rack

Since cranes can move vertically and horizontally simultaneously, a good balance between rack height and length can help to reduce travel times. In this study three configurations are assumed. The first configuration consists of 10 bays, and 10 levels; the second has 5 bays and 20 levels; and the third one has 20 bays and 5 levels (Figures 2, 3, 4).

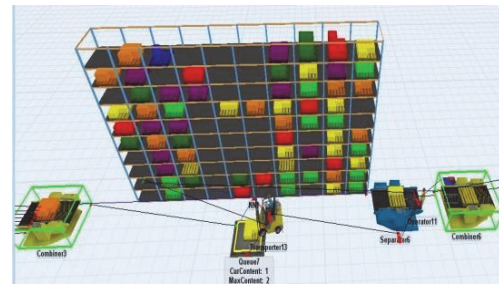


Figure 2: Rack with 10 bays and 10 levels.

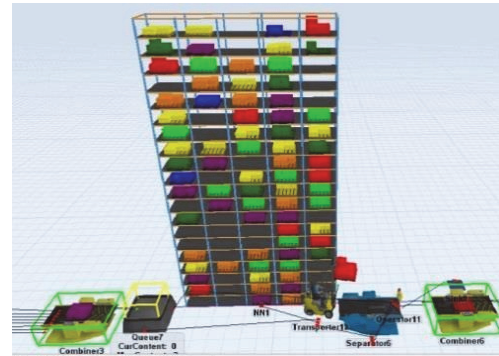


Figure 3: Rack with 5 bays and 20 levels.

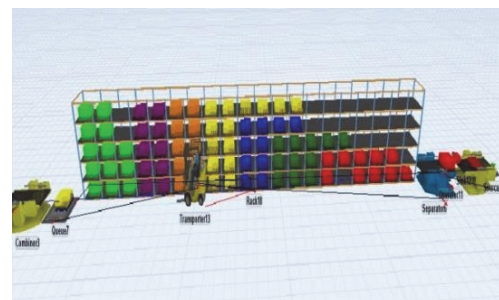


Figure 4: Rack with 20 bays and 5 levels.

### 3.3 Input/Output Station

An input station is the location where incoming products are received from other parts of the warehouse by for example, automated guided vehicles, conveyors, or forklift trucks, before they are stored. An output station is where retrieved products are unloaded before being moved to shipping. In this End-of-Aisle model, it is assumed the output station is at the end of the aisle. For the input station however, two different positions are assumed, one in the first bay of the rack and a second one in the middle of the rack (Figure 5).

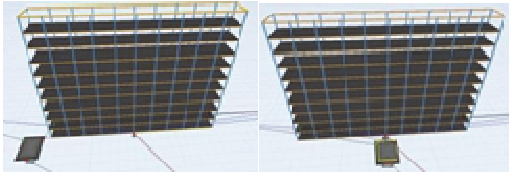


Figure 5: Location of input station: in the first bay (a), in the middle of the rack (b).

### 3.4 Storage Assignment Policies

In this model two storage policies are considered, i.e. random storage and class-based storage. For random storage, every incoming pallet is assigned to a location in the racks that is selected randomly from all eligible empty locations with equal probability (Figure 6). For class-based storage the racks and pallets are divided into K classes based on their turnover frequency. Pallets with higher demand frequency are assigned to class I while pallets with smaller demand frequency are assigned to class II and so on. The position of class I is the best location close to the Output station. For class II the position is the second best location near the Output station (Figure 7).

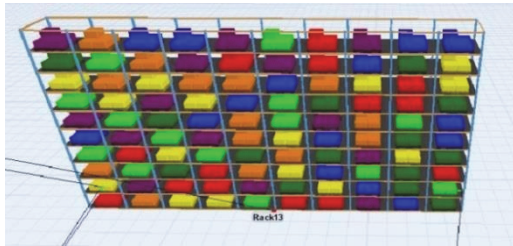


Figure 6: Random-based storage.

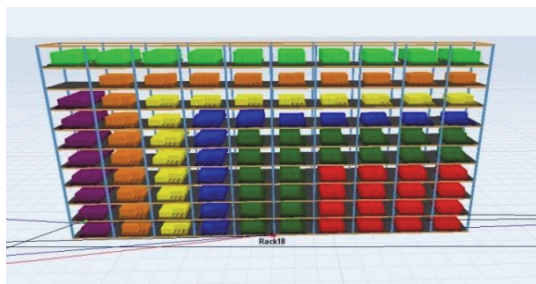


Figure 7: Class-based storage.

### 3.5 Dwell Point Policy

When the crane is idle, its location is called as the dwell point. Choosing a proper dwell point can minimize the expected travel time for the next operation. In this model three dwell points are

considered: at the Input station, in the middle of the aisle and at the Output station respectively (Figure 8).

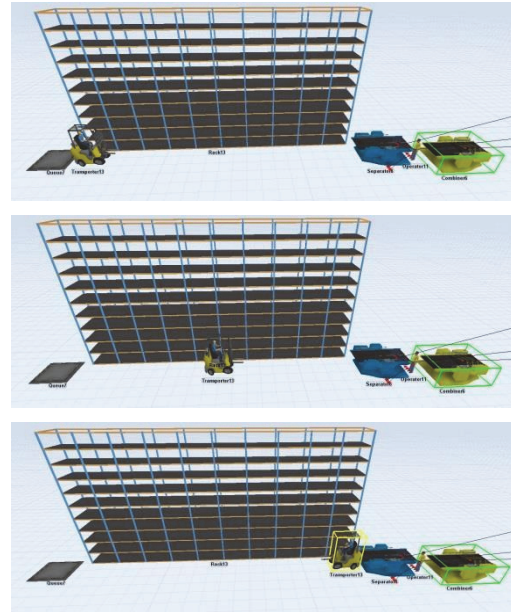


Figure 8: Position of crane: in the Input station (a), in the middle of the rack (b), in the Output station (c).

## 4 SIMULATION RESULTS

The simulation results are given in the following tables. For each storage policy – i.e. random storage and class-based storage different physical designs are analyzed for five arrival rates of pallets. Specifically, for each case the performance of the system is evaluated according to dwell point, input station and rack configuration. Each simulation is run for 3600 seconds. The measures of performance are: total travel time of the crane and total number of storages and retrievals performed by the system.

To evaluate the performance of the model, the simulation was initiated with storage rack utilization at zero (rack is completely free). Considering the nature of random storage, the simulation results are based on 40 replications for each scenario, and the average results are reported. Results of the experiments can be read from Table 1 and 2.

In the following subsections we will discuss the results.

### 4.1 Total Travel Time of the Crane

The following plot indicates that the total travel time increases significantly when the number of



Table 1: Total crane's travel and total number of storage and retrievals for Random Based Storage.

Dwell Point	Input station	Rack B*L	Arrival rate (pallets/h)									
			25		40		60		80		100	
			TT	S/R	TT	S/R	TT	S/R	TT	S/R	TT	S/R
Input	first	20*5	1758	35	3017	57	4326.4	77	4571.5	78	4603.9	82
Input	middle	20*5	1155	36	2013	58	3043.2	84	3563.8	103	3733.5	110
Output	first	20*5	1798	35	3075	57	4366.2	77	4619.2	78	4679.6	82
Output	middle	20*5	1154	36	2025	58	3042.3	84	3554.7	103	3732.6	110
Middle	first	20*5	1778	35	3037	57	4346.2	77	4591	78	4627.8	82
Middle	middle	20*5	1136	36	1994	58	3023.9	84	3534.3	103	3710.3	110
Input	first	10*10	866	36	1496	58	2248.5	84	2963.4	108	3245.7	122
Input	middle	10*10	526	36	970	59	1380.7	83	1779.5	109	2049.3	131
Output	first	10*10	885	36	1516	58	2148.3	84	2822.6	108	3265.9	122
Output	middle	10*10	525	36	969	59	1379.6	83	1778.3	109	2047.5	131
Middle	first	10*10	875	36	1506	58	2258.2	84	2973.3	108	3255.9	122
Middle	middle	10*10	517	36	961	59	1371.4	83	1770.1	109	2037.3	131
Input	first	5*20	415	36	735	60	1094.6	83	1440.5	109	1685.6	131
Input	middle	5*20	223	36	441	60	583.96	84	739.89	109	863.22	132
Output	first	5*20	425	36	745	60	1104.4	83	1450.3	109	1696.4	131
Output	middle	5*20	222	36	420	60	579.46	84	738.34	109	861.62	132
Middle	first	5*20	420	36	740	60	1099.5	83	1445.4	109	1689.8	131
Middle	middle	5*20	219	36	417	60	579.46	84	735.39	109	858.58	132

Table 2: Total cranes travel time and total number of storages and retrievals for Class-Based storage.

Dwell Point	Input station	Rack B*L	Arrival rate (pallets/h)									
			25		40		60		80		100	
			TT	S/R	TT	S/R	TT	S/R	TT	S/R	TT	S/R
Input	first	20*5	1568	35	2583	56	4044.3	81	4561.7	100	4888.1	118
Input	middle	20*5	1091	36	1923	58	2830.4	83	3259.6	104	3608.5	124
Output	first	20*5	1564	35	2622	56	4084	81	4586.4	100	4947.9	118
Output	middle	20*5	1087	36	1906	58	2820.3	83	3287.1	104	3604.6	124
Middle	first	20*5	1587	35	2570	56	4064	81	4553.6	100	4907.9	118
Middle	middle	20*5	1078	36	1903	58	2810.4	83	3270.8	104	3585.5	124
Input	first	10*10	758	36	1311	59	1992.8	84	2616.2	107	2944.2	128
Input	middle	10*10	574	36	991	59	1402	84	1834.5	109	2083.7	130
Output	first	10*10	735	36	1331	59	2012.5	84	2636	107	2968.3	128
Output	middle	10*10	570	36	987	59	1398.3	84	1830.3	109	2079.6	130
Middle	first	10*10	757	36	1252	59	2002.5	84	2626	107	2958.1	128
Middle	middle	10*10	564	36	981	59	1392.5	84	1824.4	109	2073.1	130
Input	first	5*20	351	36	623	59	943.71	84	1348.8	109	1509.1	132
Input	middle	5*20	255	36	442	60	589.27	84	756.28	109	849.68	133
Output	first	5*20	328	36	633	59	953.48	84	1358.6	109	1518.8	132
Output	middle	5*20	251	36	438	60	585.22	84	759.94	109	845.64	133
Middle	first	5*20	356	36	628	59	948.50	84	1353.6	109	1513.9	132
Middle	middle	5*20	250	36	437	60	584.16	84	758.88	109	844.58	133

arriving pallets to the system change from 25 to 60, but for higher rates of incoming pallets from 60 to 100, the total crane's travel time rises slowly and become more stable.

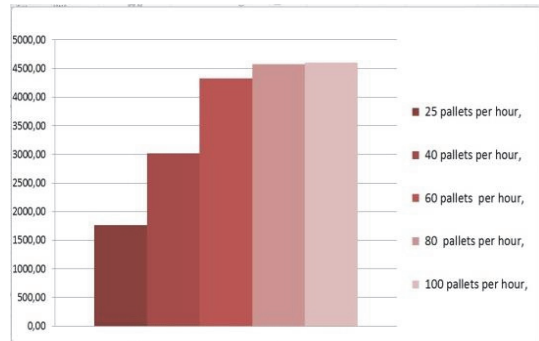


Figure 9: Total crane's travel times for different arrival rates.

#### 4.2 Random based Storage Vs. Class-based Storage

Based upon the crane's travel time and the number of storages and retrievals carried out by the system, the analysis demonstrates that class-based storage offers a better performance than random based storage. The comparison between both types is given in Figure 11 and Figure 12.

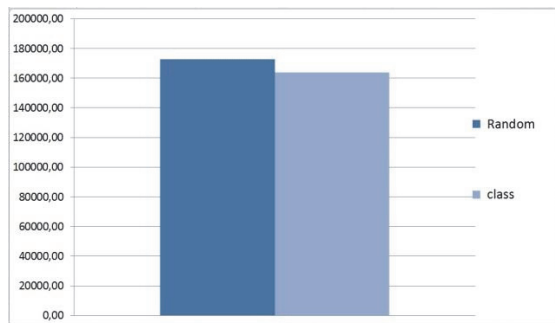


Figure 10: Total travel times for random and class-based.

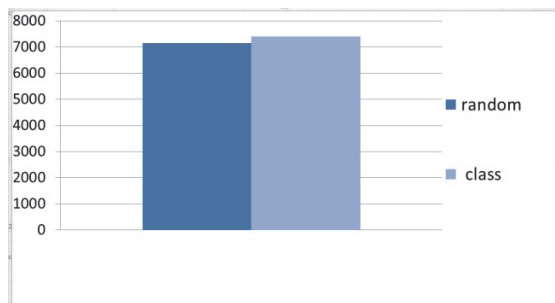


Figure 11: Number of storages and retrievals for random and class-based.

#### 4.3 Rack Configuration

The result obtained for different configurations indicate that with increasing in the number of bays, the total travel time increases and the total number of storages and retrievals increase. figures (13, 14).

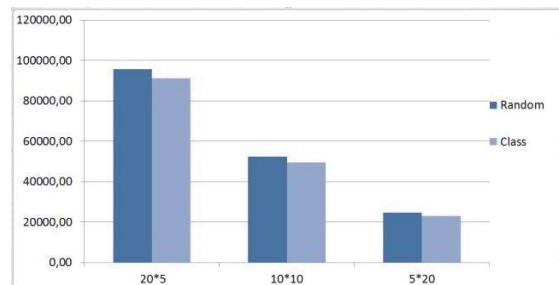


Figure 12: Total crane's travel time.

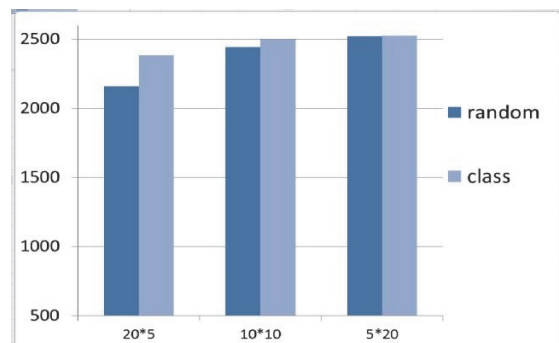


Figure 13: Total number of storages and retrievals.

#### 4.4 Input Station Location

According to the results it can be observed that the best location for dock, is at the middle of the rack. The given diagrams illustrate the total travel distance and total number of retrievals and storages

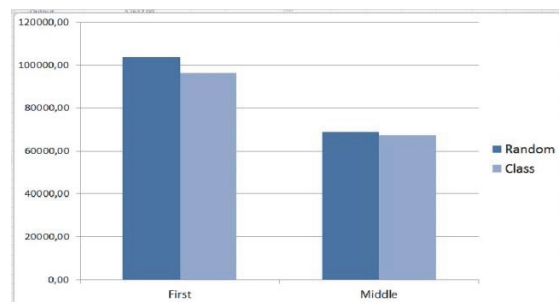


Figure 14: Total crane's travel time.

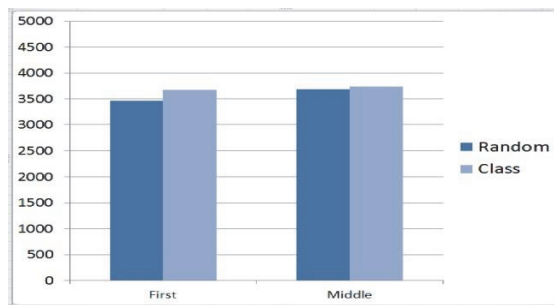


Figure 15: Total number of storages and retrievals.

#### 4.5 Dwell Point Location

The results achieved by the simulation model, reveal that the position of dwell point has negligible impact on both travel time and number of storage and retrievals. The following figures represent the comparison for three dwell point locations.

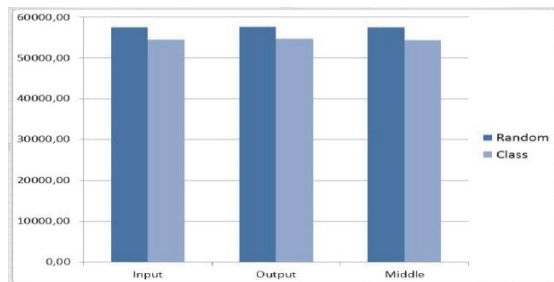


Figure 16: Total crane's travel time.

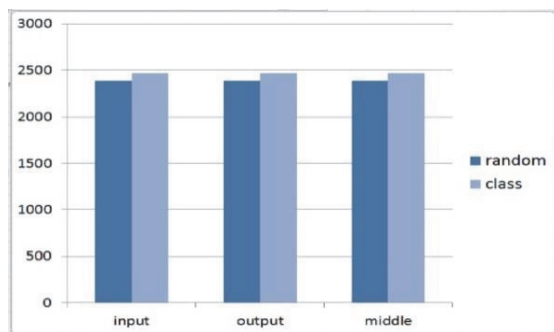


Figure 17: Total number of storages and retrievals.

## 5 CONCLUSIONS

This paper presents a simulation based performance analysis of an End-of-Aisle automated storage and retrieval system. Results of different control policies and physical designs were compared. In particular, the efficiency of the system for two types of storage, namely class-based and random based,

with combinations of different dwell points, Input locations and various rack configurations, were analyzed. This preliminary analysis shows that combination of class-based storage with an input station in the middle of the rack, seems to provide a superior performance. The analysis with other strategies is ongoing.

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